The Wide-Field X-ray Telescope

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DETF White Papers on Clusters

Vikhlinin et al.

PROBING DARK ENERGY WITH CLUSTER EVOLUTION
IN A 10,000 SQUARE DEGREE (“10K”)
X-RAY SURVEY

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The growth of structure and the distance-redshift relation are the primary observables for constraining the dark energy equation of state. Clusters are highly sensitive to the growth of structure and a large survey to $z \sim 1-1.5$ can effectively constrain the equation of state for dark energy. Because the measured mass function is inherently distance-dependent, the cluster survey can combine the growth of structure and distance-redshift tests in a single experiment.

Massive clusters, the ones most suitable for cosmological studies, are easily detectable in X-rays to $z \sim 1.5$ (beyond which they disappear due to evolution). We propose a project implementing, with a single X-ray telescope, a sensitive survey of 10,000 deg^2 and deeper follow-up observations of ~ 1000 detected massive high-z clusters to measure their masses with uncertainties sufficient for accurate dark energy equation of state constraints.

A limiting flux for cluster detection will be 2×10^{-14} erg s^{-1} cm^{-2}, yielding $\sim 50{,}000$ clusters in the 10,000 deg^2 survey. From these, we will select a complete sample of clusters to $z \simeq 1.5$, with masses greater than $4 \times 10^{14}\,h^{-1}\,M_\odot$. The mass limit is chosen to minimize non-gravitational effects on the cluster gas (e.g., energy input from SNe and AGNs). At $z = 1.5$, the limiting mass corresponds to a minimum flux of 7×10^{-14} erg s^{-1} cm^{-2}, yielding an easily detectable 70 net source counts in 5 ksec exposures. These clusters will be followed up with longer exposures, to obtain 1500 photons for each object, allowing individual mass estimates with 20% accuracy. We demonstrate that the derived mass functions in the redshift shells $0.4 < z < 0.6$, $0.9 < z < 1.1$ and $z \sim 1.5$ will constrain w to ± 0.06 at $z = 0.2$, including reasonable systematic errors. The full sample would provide still stronger constraints.

Achieving the required X-ray sensitivity is not technically challenging. The proposed project can be carried out with a telescope similar to that developed in 1999 in a collaborative investigation by SAO and Osservatorio Astronomico di Brera. The baseline design contains a 50 shell, light weight Wolter optic with an outer diameter of 70 cm and a focal length of 3.5 m, with an effective area of 670 cm^2 at 1.5 keV, angular resolution better than 15″ (half energy width) over a 1.4 deg^2 FOV. The total weight of the scientific payload is under 400 kg.

We estimate that this mission could be built on a timescale of 4 to 5 years once funding is approved. The only long lead time component is the manufacture and assembly of the X-ray telescope. The X-ray survey, optical follow-up, and X-ray follow-up will be interleaved and will be completed within 2.7 years.

Haiman et al.

An X-ray Galaxy Cluster Survey for Investigations of Dark Energy
a White Paper submitted to the Dark Energy Task Force, 15 June 2005
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The amount and nature of dark energy (DE) can be tightly constrained by measuring the spatial correlation features and evolution of a sample of $\sim 100{,}000$ galaxy clusters over the redshift range $0 < z \lesssim 1.5$. Such an X-ray survey will discover *all* collapsed structures with mass above $3.5 \times 10^{14} h^{-1} \mathrm{M}_\odot$ at redshifts $z < 2$ (i.e. the full range where such objects are expected) in the high Galactic latitude sky. Above this mass threshold the tight correlations between X-ray observables and mass allow direct interpretation of the data.

DE affects both the abundance and the spatial distribution of galaxy clusters. Measurements of the number density $d^2N/dMdz$ and the three–dimensional power spectrum $P(k)$ of clusters are complementary (have different parameter degeneracies) to other DE probes, such as Type Ia SNe or CMB anisotropies, and precisely constrain cosmological parameters.

The abundance dN/dz and power spectrum $P(k)$ of collapsed dark matter halos are theoretically computable from ab–initio models, with no free parameters (other than cosmology). Uncertainties in the relation between the halo mass and the observable X-ray flux can be overcome through a process of self-calibration, taking advantage of the synergy between the two observables. While clusters are highly biased tracers of the mass distribution, the bias is calculable from the same simulations that derive the mass function. Hence the large bias is a bonus - it increases the signal–to–noise of the $P(k)$ measurement by a (mass limit dependent) factor of 10-100.

X-ray emission is an efficient and robust way to identify clusters. Imaging X-ray cluster surveys have high and well understood completeness, low rates of contamination, and the selection function is well understood without complex simulations.

The DE investigations that we describe can be performed with a survey of 20,000 deg^2 to a 0.5–2 keV flux limit of 2.3×10^{-14} erg cm^{-2} s^{-1}. At this flux the X-ray sky is dominated by clusters and AGN, which can be separated with an angular resolution of 15 arcsec. The number–flux relationship is well known to the proposed depth (Gioia et al. 2001; Rosati et al. 2002). The proposed survey, consistent in technical scope with a NASA Medium Explorer mission, will identify $\sim 100{,}000$ clusters. Multi-band optical surveys to provide the required photometric redshifts are already in the planning stages, and will be contemporaneous with or precede our X-ray survey.

Key Features

- Constant 5” PSF across 1 degree FOV
- Effective area ~ 6X Chandra
- Bandpass: 0.5-3 keV
- Dedicated survey mission (no GO program), calibrated data products released with no proprietary period
- Will serve as a target finder for future X-ray missions
- Total cost ~ $600M

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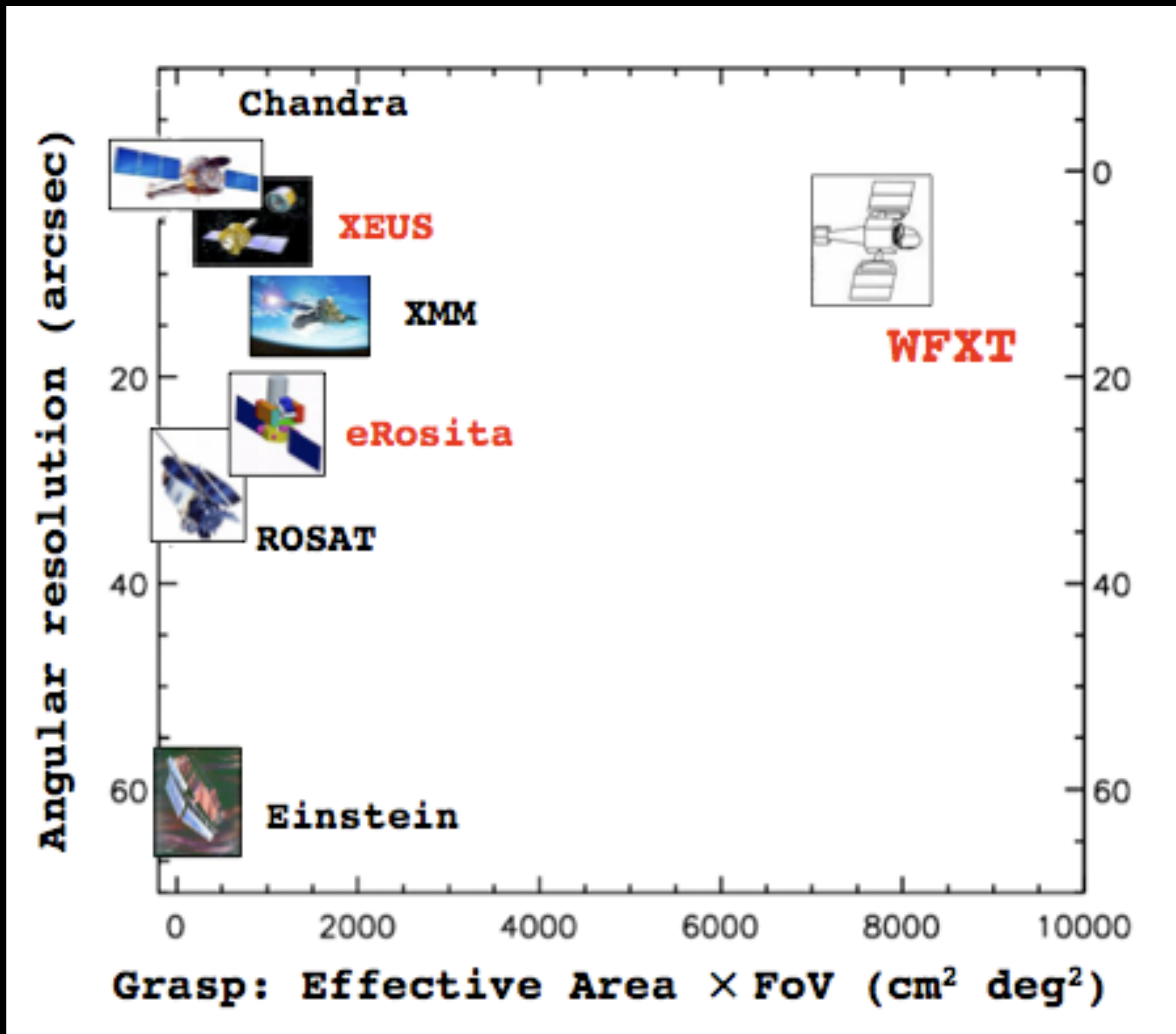
	WIDE	MEDIUM	DEEP
Area (deg^2)	20000	3000	100
$F_{lim,ext}$	4×10^{-15}	1×10^{-15}	1×10^{-16}
$F_{lim,pt}$	1×10^{-15}	2×10^{-16}	1.5×10^{-17}

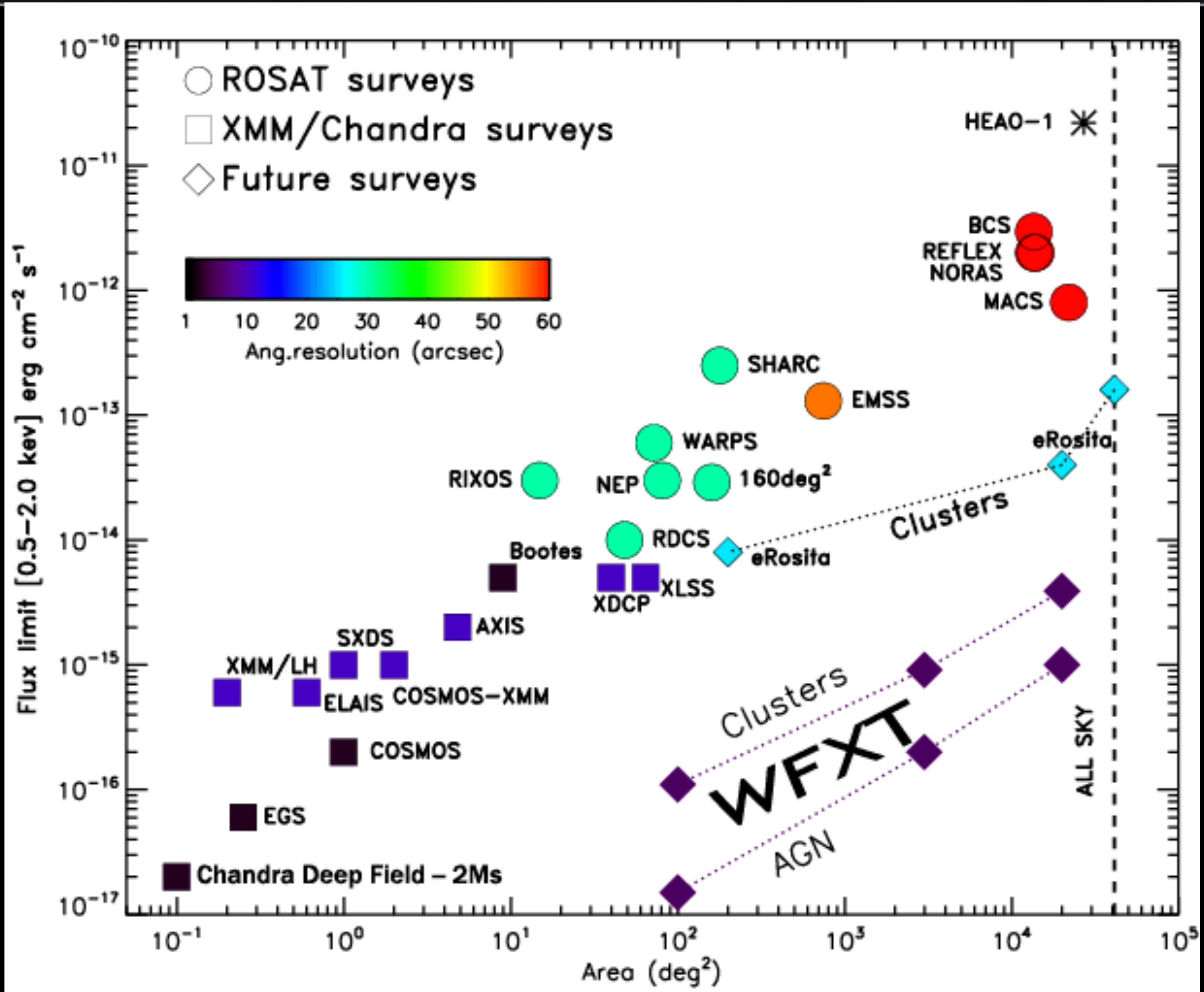
Technical Requirements

Mission Component	Requirement	Goal
Ang. Resolution	5”	3”
Energy Band	0.2-3 keV	0.2-6 keV
Effective Area (cm^2)		
1 keV	5000	10000
2 keV	5000	10000
4 keV	3000	7000
Field of View	1 degree	1.5 degree

Grasp

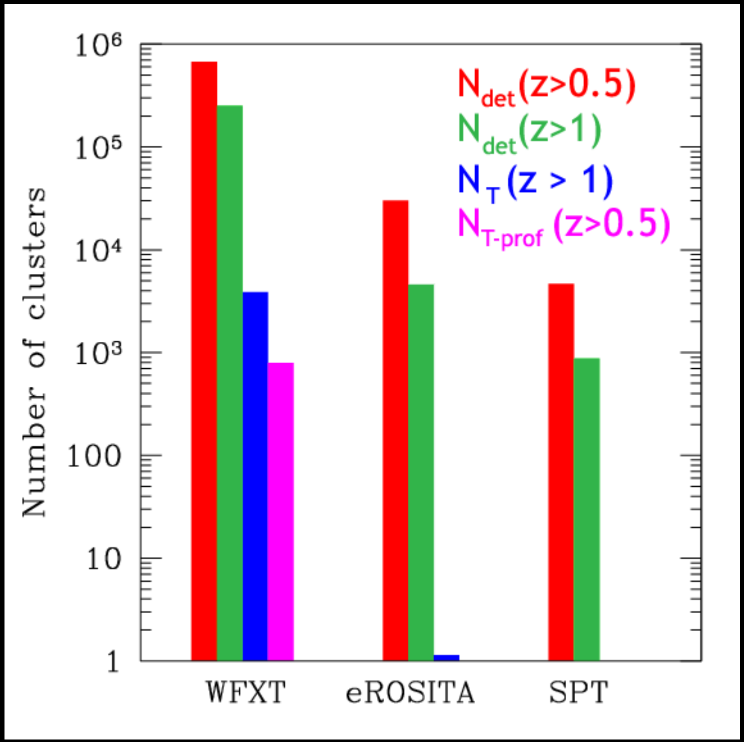

Chandra
XEUS
XMM
eRosita
ROSAT
Einstein
WFXT
Angular resolution (arcsec)
0
20
40
60
0
2000
4000
6000
8000
10000
Grasp: Effective Area × FoV (cm² deg²)

Science Highlights

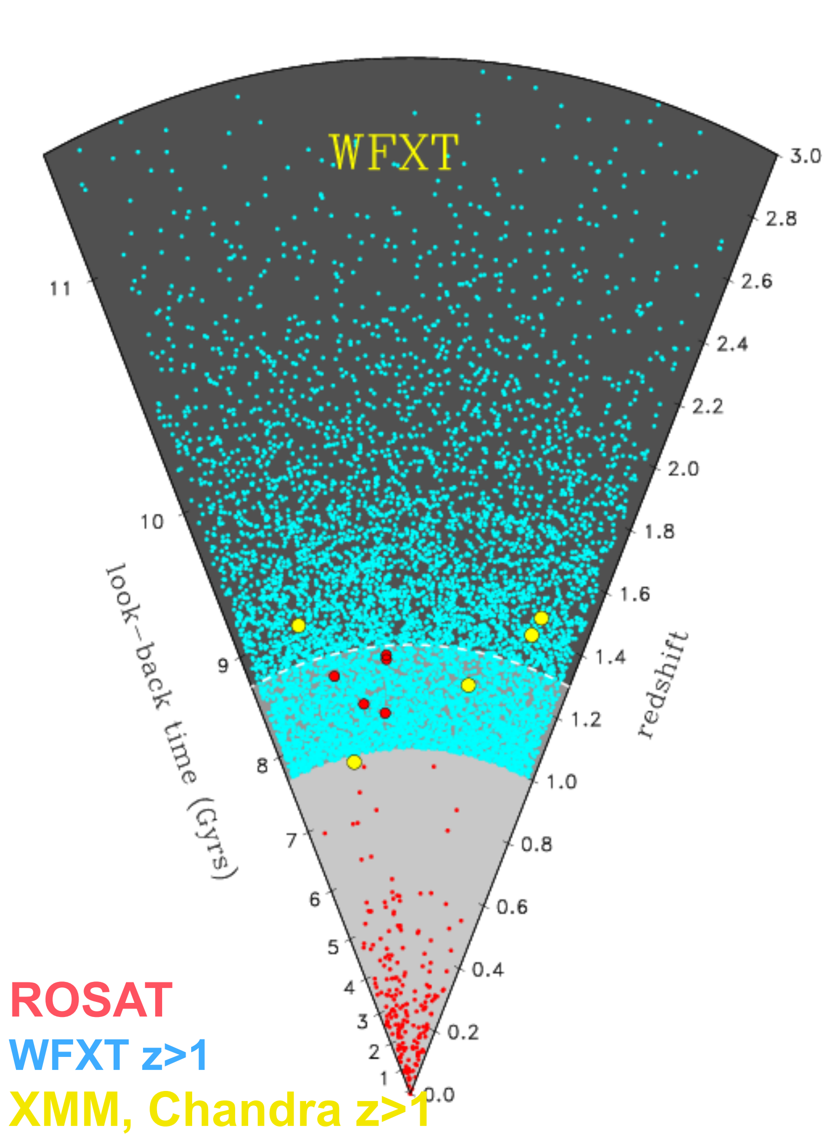


Science Highlights: Clusters

- $>10^5$ clusters detected
  - Mass functions and their evolution
  - ICM spectra for $>10^3$ (ICM physics)
- Synergy with dark energy missions will constrain Ω_M and Ω_λ

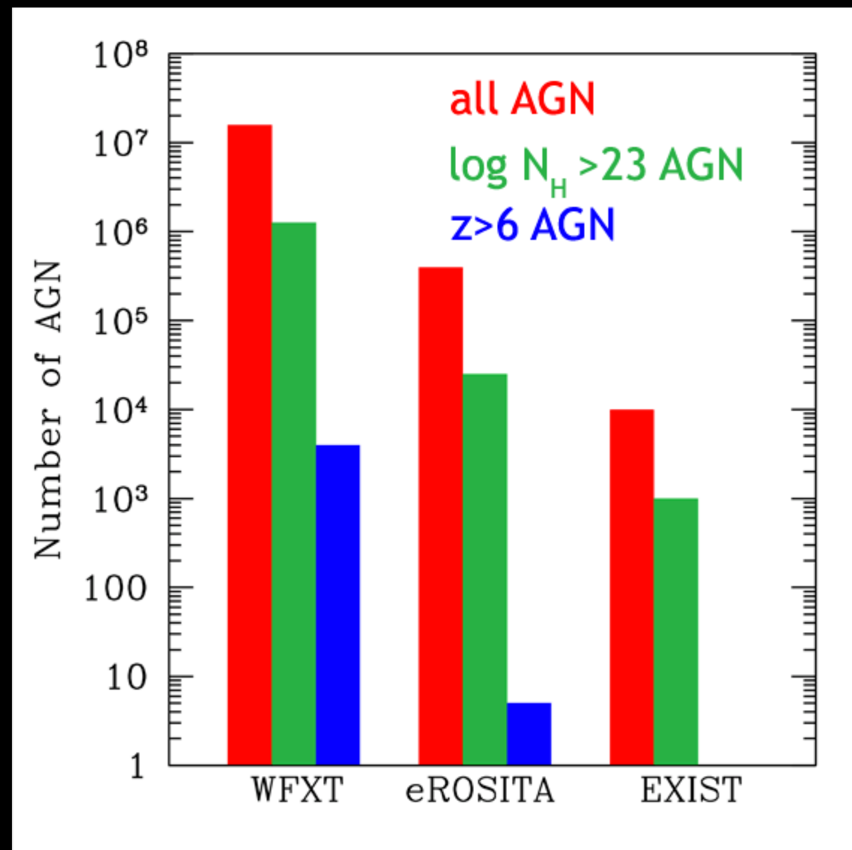


SPT = South Pole Telescope S-Z clusters



Science Highlights: AGN and Galaxies

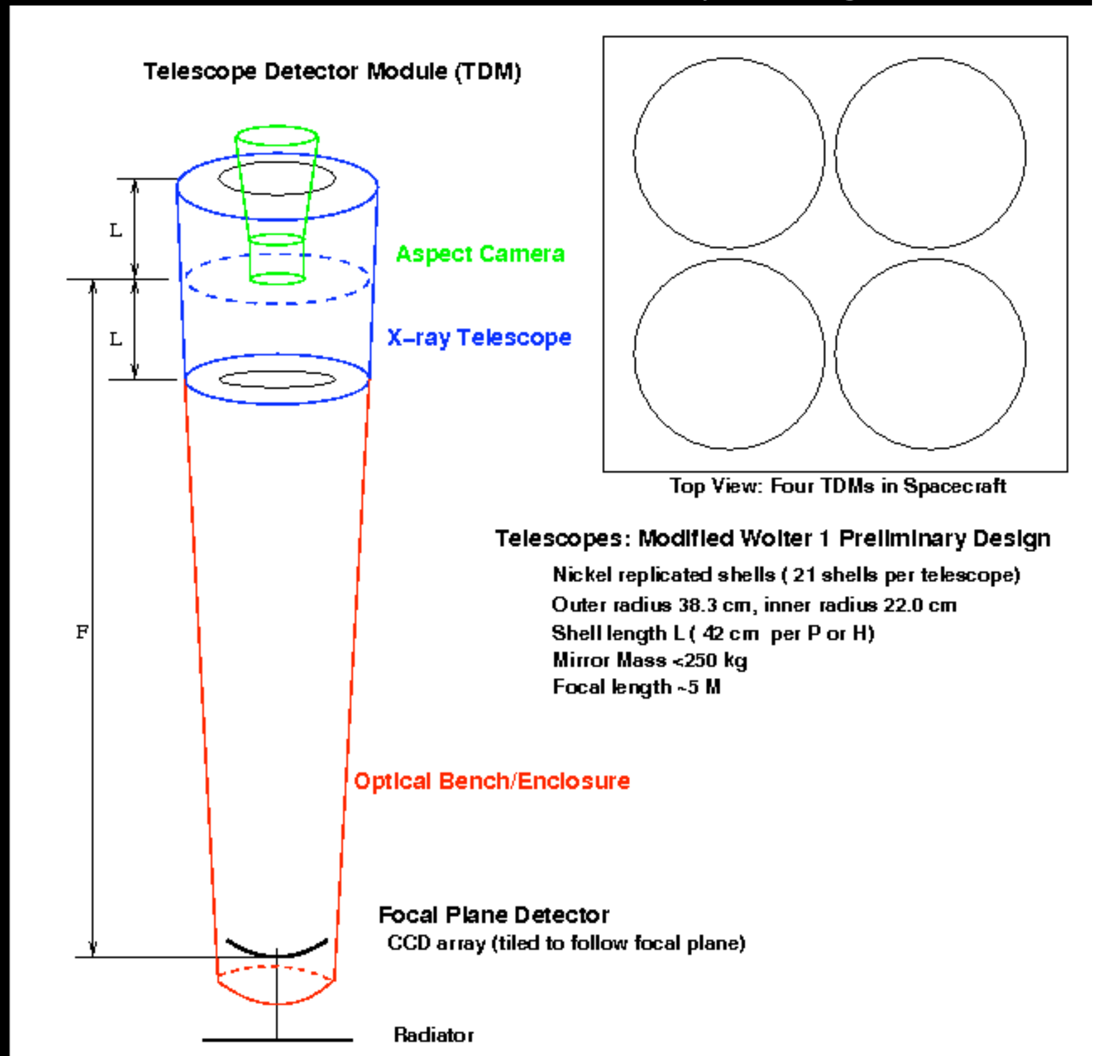
- *WFXT* will be an "X-ray *GALEX*", detecting $>10^7$ AGN, $>10^5$ galaxies
  - Minimal bias
  - Environment and evolution
- Variability in AGN, galaxies (XRB and tidal captures)
- Deep survey will reach CDF depths



Technology Plan

- Burrows, Burg & Giacconi (1992) polynomial perturbation optics design
- Electroformed nickel replication (best multi-shell performance to date ~ 18")
- Developing wide-field optics and optimizing the complete system with end-to-end modeling
- Detectors: CCD or CMOS

WFXT Preliminary Design



Status

- Awarded internal funds for early development
- Will present white paper to Decadal Survey committee in 2009
- Missions of this modest scale are very powerful & *vital* to our progress